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TRANSONIC FLOW PAST PROJECTILES WITH VARIABLE NONAXISYMMETRIC CROSS SECTION

by

Stephen S. Stahara

Final Report

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Prepared under Contract No. DAAG29-77-C-0038

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U.S. ARMY RESEARCH OFFICE
Research Triangle Park, NC 27709

by

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A summary report is provided of the work performed under U.S. Army Contract No. DAAG29-77-C-0038. This work relates to the development of a predictive method for determining the steady inviscid aerodynamic behavior of ballistic projectiles throughout the transonic range. The development has been directed toward establishing the theoretical capability for predicting the static stability characteristics of both the standard conical boattail projectiles as well as a variety of new nonaxisymmetric boattail shapes under study of the U.S. Army. Provided in the report is a concise statement of the problem

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studied, a detailed summary of the important research results, and a reference list of the publications.

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ABSTRACT

A summary report is provided of the work performed under U. S. Army Contract No. DAAG29-77-C-0038. The work relates to the development of a predictive method for determining the steady inviscid aerodynamic behavior of ballistic projectiles throughout the transonic range. The development has been directed toward establishing the theoretical capability for predicting the static stability characteristics of both the standard conical boattail projectiles as well as a variety of new nonaxisymmetric boattail shapes under study by the U. S. Army. Provided in the report is a concise statement of the problem studied, a detailed summary of the important research results, and a reference list of the publications.

TRANSONIC FLOW PAST PROJECTILES WITH VARIABLE NONAXISYMMETRIC CROSS SECTION

1. INTRODUCTION

This is the final summary report under Contract No. DAAG29-77-C-0038 for the U. S. Army Research Office. All of the important results of the research performed under this contract have been reported in the open literature, both in scientific journals and as technical papers at scientific meetings. These literature references are provided in Section 3 below. This summary report provides a statement of the problem studied, a descriptive summary of the most important results, a list of all publications and technical reports published, and a list of all participating scientific personnel.

2. STATEMENT OF PROBLEM STUDIED

The problem toward which the research under this contract was directed is the development of a theoretical analysis for the prediction of the flow properties and the aerodynamic characteristics of steady inviscid transonic flows past certain classes of ballistic projectiles having various boattail shapes. These shapes include both the now standard conical boattail shape as well as a variety of new nonaxisymmetric boattail shapes that are under current study by the U. S. Army. The overall objective has been the enablement of rational modeling of the transonic aerodynamic effects of incorporating different boattail geometries into ballistic projectile design, with a view toward optimizing aerodynamic performance, such as increasing range and/or payload, while simultaneously avoiding stability problems.

3. SUMMARY OF IMPORTANT RESEARCH RESULTS

The important results obtained under this contract are as follows:

3.1 Development and Verification of the Basic Theoretical Procedure for Predicting the Flow Properties of the Three-Dimensional Transonic Flow Past Axisymmetric and Non-Axisymmetric Ballistic Projectile Shapes.

The basic theoretical method employed to determine the transonic flow field past these projectile configurations is the

transonic equivalence rule (TER). The procedure provides the means for simplifying, under certain conditions, the three-dimensional transonic flow past slender aerodynamic configurations into a series of simpler two-dimensional problems.

One of the basic tasks of this study was to verify the accuracy and range of validity of the TER procedure as applied to slender shapes in general, and to projectile-like shapes, in particular. This verification was accomplished and is reported in reference 1 below. That study represented the most detailed and extensive assessment of the classical TER made to date. Extensive comparisons of TER theoretical results were made with data that was obtained in conventional transonic tunnels for various slender bodies, as well as for a thin triangular wing of unit order aspect ratio. Results are reported for surface and flow field pressure distributions at Mach numbers throughout and beyond the transonic range for both nonlifting and lifting conditions. The comparisons with experiment display good agreement, including the region near shock waves, and indicate that the classical equivalence rule approximation remains effective for certain three-dimensional aerodynamic configurations over a broad range of geometries and flow conditions.

3.2 Development and Verification of a Transonic Wind Tunnel Interference Assessment Procedure for Axisymmetric Flows

In order to carry out the evaluation of the TER method described in Section 3.1 above, it was necessary to use experimental data in the transonic regime that were obtained in conventional ventilated wall transonic wind tunnels. Because of the slenderness of the configurations tested, in order to achieve the desired transonic conditions, it was necessary to test at oncoming Mach numbers at and quite close to unity. Consequently, the presence of tunnel interference in certain of the data was both unavoidable and large, and it was necessary for attaining the accuracy required in the evaluation of the comparisons between the data and theory to take into account the wall effects in the theoretical results.

While the classical homogeneous wall boundary conditions commonly used in theoretical prediction of subsonic tunnel flows provide a convenient way of approximating tunnel wall effects at subsonic speeds, the approximation is grossly inadequate at transonic speeds. An alternative tunnel interference assessment procedure that was developed and evaluated represents a far more accurate and rational predictive means of accounting for wall effects. The procedure consists of employing as an outer

boundary condition an experimentally measured pressure distribution along a convenient control surface located somewhat inward from the actual tunnel walls so as to be removed from local wall disturbances. In references 2 and 3, the procedure is extensively evaluated for axisymmetric flows in the transonic regime at conditions where tunnel interference is high and where the experimentally measured conditions on the control surface are of mixed subsonic/supersonic type. Based on the transonic small-disturbance equation, results for surface and near flow field pressure distributions were determined for a variety of different slender-body shapes. These calculations demonstrate both the accuracy of the procedure as well as its ease of implementation.

Although this development is an important contribution in its own right, insofar as the present projectile study is concerned, it provides both the means for establishing the basic accuracy of the TER procedure which is the foundation of the current theoretical method as well as for evaluating if necessary wall effects in future transonic tunnel tests of ballistic projectiles.

3.3 Development and Evaluation of a Novel Method for Determining the Loading Distributions on Ballistic Projectiles That Avoids Surface Integration of Pressures

The objective of the development and application of the TER procedure to ballistic projectiles was to provide the means for determining the transonic flow fields about these shapes and, subsequently, the surface pressure and the resultant steady aerodynamic forces and moments. Since the primary utility of the present predictive method to projectile applications, however, is in the accurate determination of those static aerodynamic characteristics, the calculation and subsequent integration of surface pressures predicted via the TER method over the entire projectile is an undesirable intermediate and computationally-expensive step. Consistent with the order of accuracy of the present flow solution, it is possible to formulate a procedure based on the TER solution and slender body theory which avoids that step and provides the axial loading distribution directly.

In reference 4, the development and evaluation of that procedure, based on the method of apparent masses, is presented. The evaluations are made with other theoretical predictions based on surface pressure integrations at flow conditions throughout the transonic regimes and for geometries typical of ballistic projectiles. Those evaluations indicate that the procedure is able to predict the steady transonic loading distributions on typical ballistic projectiles with good accuracy.

3.4 Development and Evaluation of a Predictive Method for Evaluating the Static Aerodynamic Characteristics of Ballistic Projectiles at Transonic Speeds

The development of the overall predictive method for investigating the steady inviscid aerodynamic characteristics of ballistic projectiles having various axisymmetric and nonaxisymmetric boattail shapes is reported in reference 4. These boattail shapes include the now standard conical boattail, as well as a variety of nonaxisymmetric shapes formed by using cutting planes on the projectile afterbody. The complete theoretical procedure employs the classical transonic equivalence rule together with the new loading calculation method based on apparent mass concepts and makes use of the nonlinear equivalence rule flow solutions. Theoretical results for static aerodynamic characteristics of a variety of projectiles have different boattail geometries are presented at flow conditions throughout the transonic range. Comparisons are made both with other theoretical methods as well as experimental results and verify the accuracy of the procedure. Computational efficiency of the method is very high, with a complete calculation at a specified M_∞ requiring approximately 20 seconds CDC 7600 CPU time, indicating high suitability for design and optimization studies.

4. REFERENCE LIST OF PUBLICATIONS

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